PATENT SPECIFICATION

DRAWINGS ATTACHED

820,814

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COMPLETE SPECIFICATION

Apparatus for Treating Living Tissue

We, UNIVERSITY OF ILLINOIS FOUNDATION, a Corporation organised under the Laws of the State of Illinois, United States of America, of 226 Illini Union, City of Urbana, State of Illinois, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention has to do with producing lesions in living tissue such as the central nervous system without the use of surgery on the tissue to be treated. (Only intervening bone may sometimes require removal.)

More particularly, the present invention provides a means for treating sharply defined localized areas of living tissue without affecting intervening or adjoining tissue.

The invention also relates to an ultrasonic radiator, subsequently designated by the word "irradiator", and more particularly to a focused type irradiator

In many instances conventional surgery is to be avoided if possible because of the accompanying surgical shock, the possibility of dangerous hemorrhage, the disturbance to intervening tissue and the possible complication of infection. Even with the most expert surgeons using modern known operating procedures, such complications are at times unavoidable. Among surgeons it is recognized that brain and spinal operations are among the most delicate which the surgeon is called upon to perform. Up to the present time brain surgery as practiced has involved either direct cutting of brain tissue, the coagulation of the tissues by the insertion of electrically excited probes into the regions to be destroyed or chemical techniques involving needle insertions.

With the contemporary development of surgical methods of treating the symptoms of painful, pyschiatric, and basal ganglion disorders the neurosurgeon is frequently called upon to produce a focal destructive lesion in the nervous system. The obvious objective in such instances is to create a localized lesion in the desired area with no damage to adjacent or intervening tissues. This ideal has, up to the present, not been attained although some experimental work has been done involving the use of a focused beam of ultrasound as reported in an article entitled "Selective Action of Ultrasound on Nerve Tissue" by William J. Fry and John W. Barnard, published in Part 6 of the 1954 Convention Record of the Institute of Radio Engineers, in U.S.A. America, put in the mail to members on June 23, 1954 to which reference is hereby made. Further work on the subject matter of the invention is reported in an article entitled "Production of Focal Destructive Lesions in the Central Nervous System with Ultrasound" by W. J. Fry, W. H. Mosberg, Jr., J. W. Barnard, and F. J. Fry, published in the November 1954 issue of Journal of Neurosurgery 11, placed in the mail December 31, 1954, to which reference is also made.

Ultrasound can be focused by single or multiple lens system, by reflector systems, or by a combination of both. The size of the focal spot or region in such a system is determined by the wave length of the sound, the focal length of the focusing system and the aperture of the focusing arrangement. For the production of deep-seated lesions in living tissue, such as the brain, as well as for the treatment or observation of such tissues, it is often desirable, particularly for some positions in the brain, to use multiple focusing beams rather than a single beam. Focused multiple beams of the same convergence angle have an advantage because the skull bone must be removed before treatment of such tissues by ultrasound and in many instances it may be easier to prepare surgically an opening for admitting a number

of focused individual beams than it would be to prepare, that is, remove enough bone to admit a single large beam. Furthermore, it may be easier to produce changes in the tissue at various positions in the brain by an arrangement of multiple beams in that the number of beams used can be chosen to fit the particular situation.

The present invention provides means for treating sharply defined localized areas of living tissue without affecting intervening or adjoining tissue which comprises means for irradiating the tissue with a focused ultrasonic beam having a frequency of at least 20 kc/sec, the acoustic energy of which is confined between two surfaces as it converges to the focal region.

The present invention further provides a focusing ultrasound irradiator comprising: a support, a housing carried by said support, a vibrating element in said housing, connnections for conducting electrical power to said element, a lens adjacent to said element for focusing the beam radiated from said element, means for adjusting said housing longitudinally with respect to said support in a direction along the axis of the beam for relative phase adjustment of the beam with respect to an arbitrary reference, such as one of the four beams, and means for adjusting said housing angularly within said support with respect to said axis for adjusting said beam in a direction perpendicular to the beam axis.

According to this invention accurately localized quantitatively reproducible focal lesions are produced in the central nervous system by the application of a focused beam or a plurality of focused or localized beams of inaudible ultrasound radiated under controlled conditions of focus, frequency, sound level (including intensity, acoustic pressure amplitude, particle velocity amplitude) and temporal conditions of exposure (duration and time sequence of single or multiple "shots"). By ultrasonic is meant frequencies above those heard by the human ear, i.e., above about 20 kc. Frequencies of the order of 1 megacycle have been found very satisfactory. By such means discrete lesions which may be destructive can be produced at appreciable depths within the tissue without disrupting effects on the blood vessels in the same region or deleterious effects on adjoining or intervening tissue. The ultrasonic waves may be continuous or pulsed.

Lesions can be produced at any desired depth in the brain, for example, without disruption of blood vessels within the site of the lesion and without deleterious disturbance of intervening or adjacent tissue. The vascular system in the lesion is not disrupted. Lesions as small as 1-2 mm. in maximum diameter can be produced. Under prescribed dosage conditions the white matter of the central nervous system is readily affected without disruption of neighboring gray matter. Gray matter can be irreversibly affected at different (higher than one megacycle per second) ultrasonic dosages than those required for affecting white matter. In a barely threshold effect as observed histologically, the myelin undergoes drastic changes but the axis cylinders do not appear to be damaged. In a more complete effect the myelin and the axis cylinders are both destroyed. In other words, a differential destruction of nerve fiber tracts as contrasted with nerve cell body regions is obtainable along with the formation of a lesion of almost any desired shape and size with sharply defined boundaries. To produce a lesion of large size it is desirable to move the focal spot either successively or continuously to a plurality of positions. If successive "shots" are used they may be taken on, for example, a rectangular pattern of the shape desired. The spacing distance between centers has been in the range 0.5 mm. to 1 mm. for much of the work done so far. Duration of each shot has ranged from 0.5 second to 10.0 seconds for much of the work done so far with the single exposure procedure. With the multiple exposure method the duration of each acoustic pulse has been as short as 0.01 second. The duty cycle may be varied from 100% down to 1%, for example.

This method may be carried out by the following apparatus. The ultrasonic beams may be produced by a plurality of transducers driven electronically by R. F. amplifiers, excited by signal generators. It is also possible to use a transducer which consists of a set of reflecting surfaces which focus or localize the acoustic energy produced by a single or multiple array of vibrating elements. This reflector method of localizing the acoustic energy is to be distinguished from the localization method consisting of a vibrating element in conjunction with a complete (entire area contributing energy at the focus) lens. The reflector method is designed to substantially confine the acoustic energy to the space between two surfaces (one enclosing the other) with a common axis. As such it is considered as the limiting case of a plurality of individual beams. An electronic switch may be inserted between the signal generator and the amplifier for controlling the duration and time sequence of the acoustic pulse or pulses which may be varied in steps of, for example, 0.001 second. Four transducers are employed in one embodiment of the apparatus, each consisting of an X-cut quartz crystal vibrated at resonance and mounted in a housing having a focusing polystyrene lens, water or oil being the coupling medium between the crystal and lens. Obviously, instead of

utilizing lenses to form the four beams, reflector systems could be utilized to obtain the same results. Means are provided for adjusting the position of the focal point of each transducer. The sound intensity, and or other acoustic variables can be adjusted by varying the driving voltage and phase adjustments with which the transducers are provided. A beam of, for example, 1.5 mm. diameter (half power width) can readily be produced at one megacycle per second and has been found satisfactory for much work. All transducers can be focused at a common point. The multiple focused beam type irradiator provides an ultrasonic beam, the intensity of which decreases very rapidly in a direction away from the joint focal region. The transducers are so mounted that the common focal point of irradiation may be moved by the operator in the directions of three rectangular co-ordinates and the axis of the beam may be oriented in a variety of angular directions.

The illustrated focused multibeam ultrasonic irradiator of this invention utilizes four individual beams, although the number is not critical, emanating from four heads, each of which may be individually adjusted and each beam of which is produced by a vibrating element, focused by a lens placed in front of the element. There is also incorporated a pointer provided with suitable adjustments which enable its tip to be brought into coincidence with the focal region of the four beams when the transducer is producing sound in a medium such as water. This pointer is also retractable without disturbing the adjustments of the four heads and may be returned to its co-incidental position to provide a reference or zero point for positioning the irradiator with respect to the tissue to be treated, such as the brain. The pointer is thereafter retractable without disturbing the setting of the four heads and is retracted during irradiation.

A more detailed description of one embodiment of the apparatus of this invention will now be given in connection with the accompanying drawings in which:

Fig. 1 is a front elevation of a four beam focusing irradiator with one (the front) head removed;

Fig. 2 is a top plan view;

Fig. 3 is a fragmentary section, taken along line 3—3 of Fig. 2; and

Fig. 4 is a vertical section taken along line 4-4 of Fig. 2.

The four beam instrument illustrated is suspended from a common carrier shown as the lower end of the tube or cap 10 by means of three arms 12 fastened at their upper ends to a plate 14, secured to a disc 16 which in turn is secured to tube 10 by screws or any other suitable means (not shown). At their lower ends arms 12 are secured by screws 13 to four brackets 18, each of which is fastened to the collars 20 of two adjacent heads of the group of four, as is more clearly shown in Figs. 1 and 2. The four collars 20 are thus carried by the tube 10 in a generally rectangular pattern and are arranged to support the four heads, inclined downwardly and inwardly toward a common focal point.

The four heads are similar in construction and, therefore, only one will be described in detail. Each head has its own vibrating element 22, such as an x-cut quartz crystal, mounted within a cup-like housing 24, sealed at its upper end by plate 26, and sealing gasket 27, bolted to the outwardly extending flange 24*a* of the housing by bolts 28. Positioned within the upper portion of the housing and substantially filling the latter is an insulating block 29, to the lower face of which is secured a metal block 30 by screws 31. The block is of lesser diameter than the housing 24, thus providing an annular channel 32 for receiving insulating oil. This channel may be filled through a duct 34 in block 29, said duct being closed by screw cap 36. In front of, that is, below the crystal 22 is a plano-concave lens 40 positioned with its plane face against or preferably slightly spaced from the lower face of the crystal. The lens may be made of polystyrene or any other suitable material, even metal. The space 41 between the crystal and the lens may be filled, for example, with de-gassed distilled water or castor oil. The crystal is sealed against the block 30 by a gasket 42 on one side and against the inturned flange 24*b* of housing 24 by gasket 42*a* upon the other side, which gaskets also serve the purpose of cushioning the crystal. The lens is retained in position by cap 43, secured to the lower end of housing 24 by screws 44. Gaskets 46 and 42*a* provide the necessary seals for the lens.

The outer face of the crystal, that is, the face adjacent the lens, is at ground potential and for this purpose a metallic foil connecting ring 50 is inserted between the outer face of the crystal and the lower inturned flange 24*b* of the housing 24. An annular collar 52 insures contact of the foil against the housing. The opposite face of the crystal, that is, its upper face, is at high potential and for this purpose, a second metal foil collar or ring 54 is placed between the upper gasket 42 and the metallic block 30 to insure good electrical contact between the crystal and the block. The gaskets 50 and 54 do not extend across the entire surface areas of the gaskets 42 and 42*a* and, therefore, do not defeat the sealing function of the gaskets. The sealing oil in the oil chamber between block 30 and the housing further insulates the block 30 and the crystal

from the housing 24. The high frequency high voltage power to the crystal is provided through an electrical lead-in 56 concentric with the axis of the housing and having a sliding contact 57 with block 30. Lead-in 56 extends axially upward and is surrounded by an insulator 58, the lower end of which is clamped between the plate 26 and the block 29 as shown in Fig. 4.

The head thus far described is provided with certain adjustments to enable the individually focused beams to be brought into coincidence at a common point. For this reason, each head is loosely mounted within a collar 20 and is supported thereby for both a longitudinal movement along its axis to vary the phase of the emanating sound waves in the coincidental focal region, and also for angular or tilting movement to vary the position of the focal region of sound radiated from the crystal in a direction perpendicular to the beam axis.

With the foregoing in mind, the head thus far described is secured to the lower outwardly flanged end 60 of a sleeve 62 by screws 64. A filler block or guide 66 is placed between the flange 60 and the plate 26 being secured to the latter by screws 68. Block 66 serves as a lower guide for the insulating sleeve 70 which surrounds and is spaced from the connector 56; the connector 56, shield 58, and insulator 70 being coaxial.

The upper end of sleeve 62 is threaded at 74 and is threadedly engaged by a knurled adjusting nut 76 rotatable between upper and lower fixed collars 78 and 79 respectively. The latter are held in spaced relation, i.e. one upon each side of nut 76 by screws 80 and ferrules 81. The lower collar 79 is secured by screws 82 to the upper end of a second sleeve 84 coaxial with and surrounding sleeve 62. Sleeve 84 terminates in a lower outwardly extending flange 86. Sleeve 62 and flange 60 are guided for longitudinal movement along its axis by pins 88 fixed in flange 60 and having a sliding fit in flange 86. Thus, sleeves 62 and 84 may slide axially one upon the other upon rotation of nut 76. The two sleeves cannot rotate with respect to each other because of pins 88. Accordingly, the crystal 22 and lens 40 can be adjusted axially for phase adjustment with respect to the other needs of the multibeam assembly.

As previously stated, provision is also made for tilting adjustment of the head. This is accomplished by providing a loose fit between collar 20 and sleeve 84 to permit tilting movement of the sleeves within collar 20. A coiled spring 90 surrounds sleeve 84 and is placed under compression between the under face of fixed collar 79 secured to the upper end of sleeve 84 and the upper face of collar 20, secured to bracket 18. A plurality of adjusting screws 92, preferably three equally spaced, are threaded through collar 20 and engage notches formed on the upper face of flange 86. Thus, by adjusting the desired one, or ones, of these screws flange 86, and therefore, the entire unit can be tilted to the desired angle within the limits of the opening on collar 20.

The multibeam irradiator is provided with a pointer 100, adjustably supported, to enable its tip to be brought into a position coincidental to the common focal region of the four heads when the transducer is producing sound in a transferring medium, such as water. That is, after the four beams are brought into coincidence, the tip of the pointer may, through suitable adjustments, be positioned at the common focal region. For this purpose, the pointer is provided with two adjustments which move the tip in a plane perpendicular to the axis of the pointer, and with an additional adjustment which permits movement of the pointer along its axis in such a manner that the pointer can be retracted and/or lowered without disturbing the set adjustment for the lower position. In this latter position the pointer provides a reference or zero for positioning the irradiator with respect to the tissue to be treated, such as the brain. The pointer is in fully retracted position during irradiation.

Pointer 100 is mounted for vertical axial sliding movement in a holder 102 and may be locked in adjusted position by a set screw 104. This position may in fact be marked, so to speak, by a square collar 106 slidingly mounted on pointer 100 and retained in said position by a set screw 108. Holder 102 has an upwardly and laterally extending arm 110 the extremity of which extends to and lies between spaced ears 112 of a clevis 114, rigidly fastened to one of the four brackets 18 by one or more screws 116. Also secured to the same bracket 18 by one or more screws 118 is an arm 120 provided with a horizontal bore 121 for sliding and rotatably receiving a horizontal cylindrical projection 122 extending from the holder 102. An adjusting screw 124 extending through the bore 121 is threadedly received in the end of the projection 122. Screw 124 also has an enlarged integral collar 126 which is engaged in the cap 128 which retains the screw against axial movement. Therefore, upon rotation of screw 124 the holder 102 and its pointer is moved horizontally in a plane, substantially perpendicular to the axis of the pointer.

The pointer may also be rotated about the horizontal axis of holder 102 as a centre by means of two adjusting screws 130 threaded through the ears 112 and engaging the sides of the terminating end of arm 110. Accordingly, pointer 100 can be tilted about the

horizontal axis of holder 102 by adjustment of screws 130. Thus, the pointer can be adjusted vertically parallel to its axis and in two horizontal directions perpendicular to its axis so that it may be located exactly at the focal region of the four heads. Its vertical position may be marked, so to speak, by locating the collar 106 against the holder 102. When it is desired to retract the pointer, screw 104 may be released, the pointer raised, and then lowered again when desired to the pre-set position by merely lowering the pointer until collar 106 again engages 102. The collar being square and one flat side engaging the upper extending portion of arm 110, the exact position of the pointer, including its rotational position, is re-located. There is thus provided a retractable pointer for physically locating and identifying the focal position of the multibeam array.

The high voltage supply to each crystal 22 is through a lead 132 connected to the upper end of lead-in 56. The four leads 132 from the four heads extend upwardly and to a common connector (not shown) located within plate 14.

If adjustments to obtain equal acoustic outputs from the individual heads are not provided, the acoustic output reached in the focal region of the individual transducers may vary somewhat from one transducer to another for equal driving voltages. Therefore, it may be desirable to provide four adjustable condensers, that is, one in series with each of the individual crystals, to adjust the voltage across the individual crystals to realize equal acoustic sound levels from each of the crystals at the common focal point. These condensers are not shown but, if found desirable the leads 132 would be connected to such condensers and not directly to the common terminal within plate 14.

To treat the tissue, that is, subject it to focused or localized and controlled ultrasonic beams, the latter are first adjusted as to focus or locus and calibrated at a given point having known co-ordinates. The tissue, such as a portion of the brain of a mammal, to be treated is supported in position for treatment in a stereotaxic apparatus. The specimen is then prepared, for example, for brain irradiation by incising the soft tissues and removing the portion of the skull in the path of the focused beam to the area of the lesion. (If bone is not present in the path that the beam must take the skin need not be opened). This assures that there is no absorption or deflection of the sound waves in their travel to the selected area. The dura mater need not be opened. The sound is preferably conducted to the tissue through sterile physiological degassed saline which offers little or no absorption or deflection of the beam. In practice it has been found practical in cases when the skin is incised to utilize a pan large enough to receive the irradiator and having a flanged opening through the bottom to which the skin (around the opening in the skull, for example) may be secured as the means for retaining the saline.

Irradiation can then proceed under the desired conditions. The depth of the lesion in the tissue can be varied by moving the irradiator vertically in the saline. Lateral placement of the lesion can be determined by moving the irradiator about on its horizontal co-ordinates. The production of a lesion at any desired location in the brain can in some cases be attained by selecting co-ordinates in accord with available charts. Extreme accuracy of relative motion between the stereotaxic apparatus and the focal spot of the focused sound beam may be achieved by having the stereotaxic apparatus and the co-ordinate system which supports the irradiator mounted rigidly on the same base.

As previously stated, sound frequencies of the order of 1 megacycle have been used with marked success at sound intensities at and above 10 watts per square centimeter and up to and over 1,000 watts per square centimeter. For certain fields of work, particularly where selective tissue changes are desired, the minimum value for the acoustic pressure amplitude should be about 5 atmospheres and the particle velocity amplitude should be at least of the order of 30 cm. per second.

In the practice of this invention moderate sized lesions of 6 mm. length in the internal capsule of cats were produced by 14 positions, 0.5 mm. apart with a dosage of about 200 watts per square centimeter for 4.0 seconds each (frequency one megacycle per second). After sacrifice of the animals the lesions were readily observed histologically and no disruption of blood vessels produced by sound was observed. Nerve cell body regions of the thalamus seemed immune to the effect of sound at the dosage used. The fibers of the internal capsule were irreversibly affected. Intervening tissue was unaffected. In other words, there was differential destruction of nerve fiber tracts as contrasted with nerve cell body regions and the formation of a lesion of the desired shape with sharp boundries.

In another instance a large ultrasonically produced lesion was obtained from a series of "shots" with a dosage of 250 watts per square centimeter for 4.0 seconds each (frequency one megacycle per second). All nerve fibers in the lesion were destroyed and sharp boundaries between degenerate white matter and intact gray matter were observed upon sacrifice of the animal.

Lesions of 2 to 3 mm. diameter may be produced, for example, by single exposure

to focused ultrasound beams (frequency one megacycle per second) by irradiation at approximately 40 atmospheres acoustic pressure amplitude and 4 $(10)^2$ centimeter per second acoustic particle velocity amplitude for 1.00 second. Such a dosage shows a sharp boundary between affected white matter and the neighboring unaffected gray matter. (The minimum size of lesion is a function of the size of the focal region. The size indicated here is that readily obtained with the transducers which produce the focal spot size indicated above.)

A greater dosage of, for example, approximately 40 atmospheres acoustic pressure amplitude and 4 $(10)^2$ centimeter per second acoustic particle velocity amplitude for 1.50 seconds produces a slightly larger lesion (using the same transducers of the preceding paragraph) containing a central area of myelinated fibers which stains normally for a considerable period of time after irradiation surrounded by a zone containing completely disrupted nerve tissue and large clear fluid-filled spaces. No hemorrhage present. No intervening tissue was disrupted in any example given.

Lesions can be produced in gray matter, but greater dosages are needed. For example, when gray matter is irradiated with a single exposure of a dosage of approximately 40 atmospheres acoustic pressure amplitude and 4 $(10)^2$ centimeter per second acoustic particle velocity amplitude for 2.50 seconds such lesions are noticed.

Obviously the apparatus described is only typical of apparatus that may be used to carry out this invention and that the specific examples of actual lesions produced and dosages applied are merely illustrative examples. Other apparatus and other lesions as well as dosages will be readily conceivable to those skilled in this art without departing from the scope of this invention as defined by the claims.

WHAT WE CLAIM IS:—

1. A focusing ultrasound irradiator comprising: a support, a housing carried by said support, a vibrating element in said housing, connections for conducting electrical power to said element, a lens adjacent to said element for focusing the beam radiated from said element, means for adjusting said housing longitudinally with respect to said support in a direction along the axis of the beam for relative phase adjustment of the beam with respect to an arbitrary reference, and means for adjusting said housing angularly within said support with respect to said axis for adjusting said beam in a direction perpendicular to the beam axis.

2. A multibeam focusing ultrasound irradiator comprising: a number of supports, a common carrier for said supports, a housing carried by each of said supports, a vibrating element in each housing, connections for conducting electrical power to each of said elements, a lens adjacent to each of said elements for focusing the beams irradiated from said elements, means for adjusting each housing longitudinally with respect to its support in a direction along the axis of the beam produced by the element in said support for phase adjustment of the beam relative to other beams or to a reference, and means for adjusting each housing angularly within said support with respect to said axis for adjusting the direction of each beam in a direction perpendicular to the axis of its beam whereby the focal points of said multiplicity of beams may be brought into coincidence.

3. A multibeam focusing ultrasound irradiator as defined in Claim 1 or 2, wherein there is an oil reservoir surrounding the periphery of said element or elements.

4. A multibeam focusing ultrasound irradiator as defined in Claim 1 or 2, wherein each of said elements and lens are supported in an axially adjustable sleeve supported from their respective housings and upon which said adjusting means operates to produce said longitudinal adjustment or adjustments.

5. A multibeam focusing ultrasound irradiator as defined in Claim 4, wherein each of said sleeves is surrounded by a second sleeve, both sleeves being adjustable within said support, said angularly adjusting means operating upon said second sleeve or sleeves to produce said perpendicular adjustment or adjustments.

6. A multibeam focusing ultrasound irradiator as defined in Claim 2, having a pointer carried thereby.

7. A multibeam focusing ultrasound irradiator as defined in Claim 6, wherein the pointer is retractable.

8. A multibeam focusing ultrasound irradiator as defined in Claims 2 and 6 or 7, having means for supporting said pointer for axial movement toward and from the focal region of said beams.

9. A multibeam focusing ultrasound irradiator as defined in Claims 2 and 6, 7 or 8 having means for tilting said pointer in a direction perpendicular to the axis of said pointer.

10. A multibeam focusing ultrasound irradiator as defined in Claims 2 and 6, 7, 8 or 9, having means for supporting said pointer for horizontal movement in a direction perpendicular to the axis of said pointer.

11. A multibeam focusing ultrasound irradiator as defined in any of Claims 6 to 10 inclusive, having means for moving said pointer in a horizontal direction perpendicular to the axis of said pointer.

12. A focusing ultrasound irradiator for

treating sharply defined localized areas of living tissue without affecting intervening or adjoining tissue which is adapted to irradiate the tissue with a focused ultrasonic beam having a frequency of at least 20 kc/sec. the acoustic energy of which is confined between two surfaces as it converges to the focal region.

13. A multibeam focusing ultrasound irradiator for treating sharply defined localized areas of living tissue without affecting intervening or adjoining tissue which is adapted to irradiate the tissue with a number of ultrasonic beams having a frequency of at least 20 kc/sec. simultaneously originating from different and spaced sources, each focused at a common focal point beneath the surface of the tissue being treated.

14. An irradiator according to Claim 12 or 13, wherein the intensity at the common focal point is at least 10 watts per square centimeter.

15. An irradiator according to Claim 13, wherein at least four focused ultrasonic beams are employed.

16. An irradiator according to Claim 12 or 13, wherein the acoustic pressure amplitude is at least 5 atmospheres.

17. An irradiator according to Claim 12 or 13, wherein the particle velocity amplitude is at least 30 cm. per second.

18. An irradiator according to Claim 17, wherein the acoustic pressure amplitude of the focused beam is at least 5 atmospheres.

19. An irradiator according to Claim 12 or 13, wherein the acoustic pressure amplitude of the focused beam is of the order of 40 atmospheres and the particle velocity amplitude is of the order of $4(10)^2$ centimeters per second.

20. An irradiator according to Claim 12 or 13, wherein the intensity at the common focal point is of the order of 250 watts per square centimeter.

21. An irradiator according to any one of Claims 12 to 20. wherein the source of the ultrasonic focused beam is movable in a predetermined pattern to define a clearly defined area of lesion.

22. A multibeam focusing ultrasound irradiator for treating sharply defined localized areas of living tissue without affecting intervening or adjacent tissue which includes at least two transducers of ultrasonic beams at a frequency of at least 20 kc, means to focus said beams at a common focal point, means to calibrate said beams at the common focal point at a known co-ordinate position, means to support said tissue to be irradiated in a known position with respect to said known co-ordinate position and means to adjust the position of said focused, calibrated and adjusted transducers with respect to the initial position co-ordinately.

23. An irradiator according to Claim 22, wherein at least four of said transducers of ultrasonic beams of a frequency of at least 20 kc are provided.

24. An irradiator according to Claim 12, 13, 22 or 23, wherein the acoustic pressure amplitude of the focused beam is at least 5 atmospheres and the particle velocity amplitude is at least 30 cm. per second.

25. An irradiator according to any of Claims 12 to 24 inclusive, which applies the ultrasound as a series of multiple exposures, at a single locus in the tissue.

26. An irradiator according to Claim 25, wherein the intensity at the common focal point is at least 10 watts per square centimeter during the exposure period.

27. An irradiator according to Claim 25, wherein the pressure amplitude in the common focal point is at least 5 atmospheres during the exposure period.

28. An irradiator according to Claim 25, wherein the particle velocity amplitude is at least 30 cm. per second at the common focal point during the exposure period.

29. An irradiator according to Claim 25 or 26, wherein the duty cycle is in the range from 1% to 100%.

30. An irradiator according to Claim 13, 22 or 23, wherein each beam is adjusted to irradiate within the same range of intensity at said focal point.

31. A focusing ultrasonic irradiator for treating sharply defined localized areas of living tissue without affecting intervening or adjacent tissue which includes a transducer of ultrasonic beam at a frequency of at least 20 kc, means to focus the beam at a focal point, means to calibrate said beam at the focal point at a known co-ordinate position means to support said tissue to be irradiated in a known position with respect to said known co-ordinate position and means to adjust the position of said focused, calibrated and adjusted transducer with respect to the initial position co-ordinately.

32. A focusing ultrasonic irradiator according to Claim 31, which applies the ultrasound as a series of multiple exposures, at a single locus in the tissue.

33. A focusing ultrasonic irradiator according to Claim 32, wherein the intensity at the focal point is at least 10 watts per square centimeter during the exposure period.

34. A focusing ultrasonic irradiator according to Claim 32, wherein the pressure amplitude in the focal point is at least 5 atmospheres during the exposure period.

35. A focusing ultrasonic irradiator according to Claim 32, wherein the particle velocity amplitude is at least 30 cm. per second at the focal point during the exposure period.

36. A focusing ultrasound irradiator constructed and adapted to operate substantially

as herein described with particular reference to the embodiments illustrated in the accompanying drawings.

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Agents for the Applicants.

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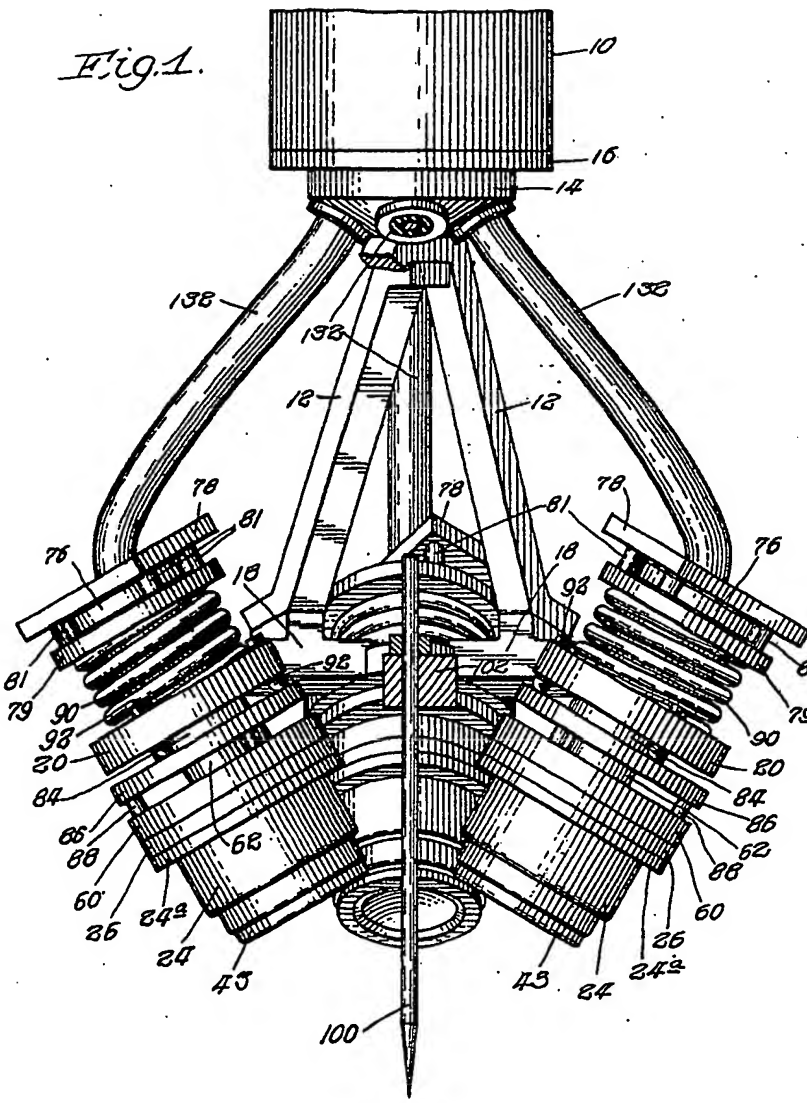
820,814 COMPLETE SPECIFICATION
3 SHEETS
This drawing is a reproduction of the Original on a reduced scale.
SHEET 1

Fig.1.



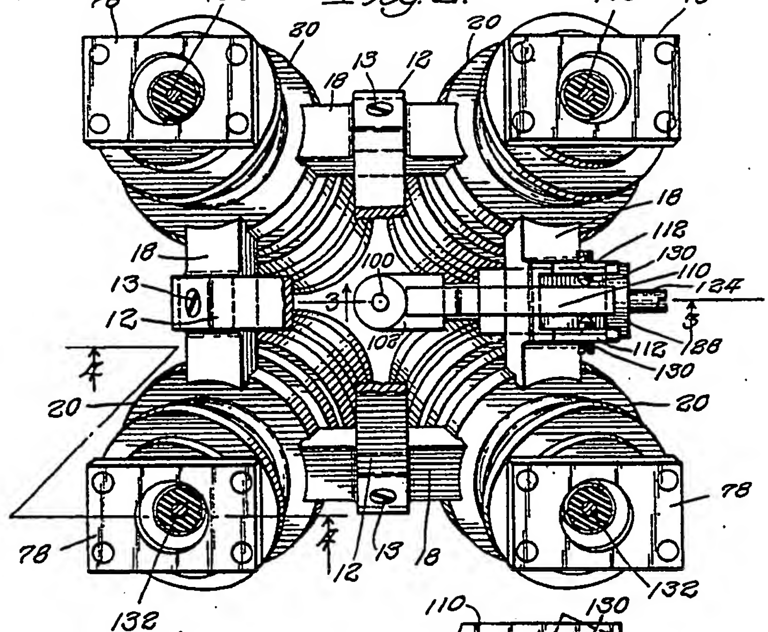

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Fig. 2.

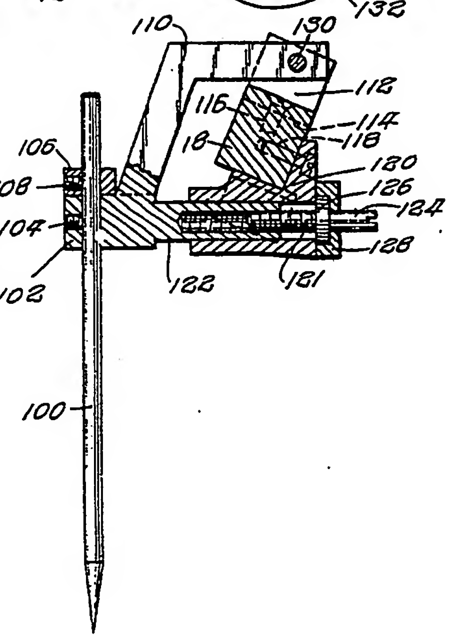
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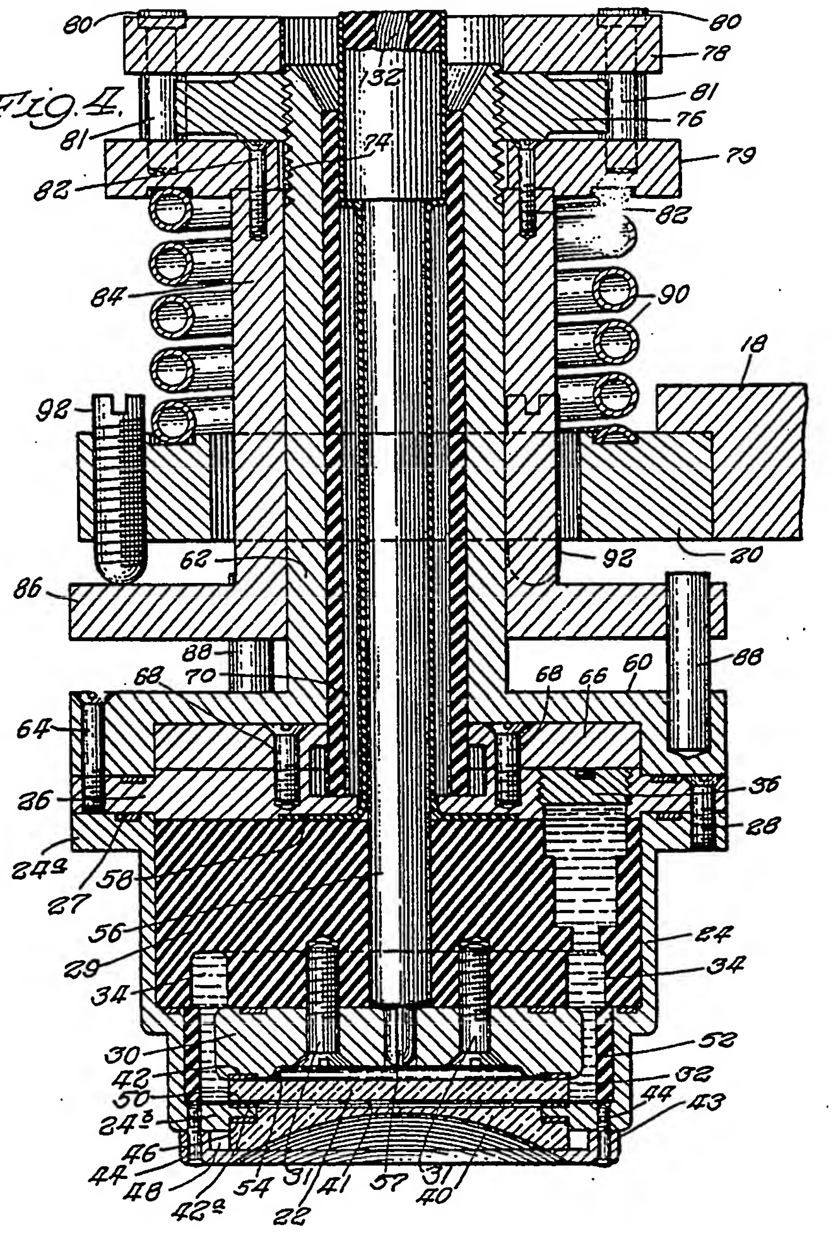
Fig. 3.

Fig.4.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43
24b
46
44
48
42a
54
31
41
57
31
40
22

820,814 COMPLETE SPECIFICATION
3 SHEETS
This drawing is a reproduction of the Original on a reduced scale.
SHEETS 2 & 3

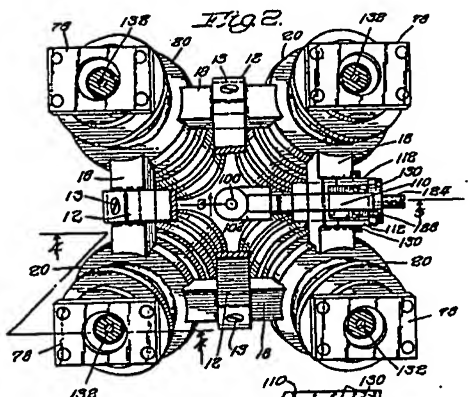
Fig.2.

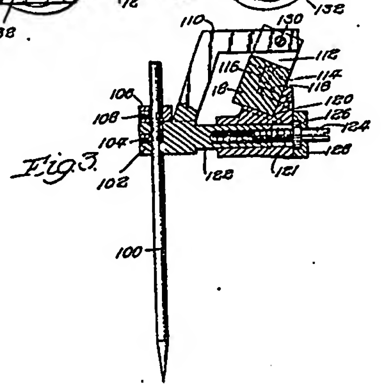
Fig.3.

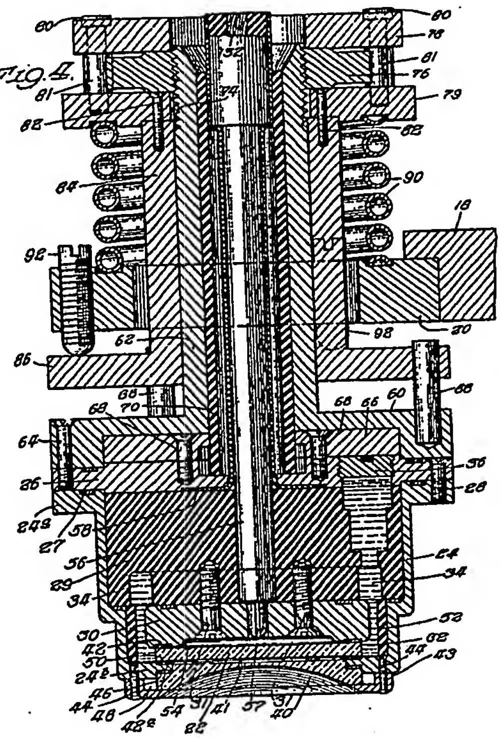
Fig.4.